

The Hadron Absorber (part of WBS 1.1.4)

Under ideal targeting conditions primary protons interact in the NuMI target and produce several species of hadrons which decay to produce neutrinos and other particles. The focusing system favors those hadrons having the desired momentum and positive charge. Non-interacting protons and secondary particles are intercepted by a hadron absorber at the end of the decay volume and give up their energy in a multi-generation cascade of interacting particles. The energy that isn't absorbed in the absorber consists mainly of muons and neutrinos that exit the rear of the absorber and enter the rock behind the absorber. A small fraction of the energy will exit the absorber as neutrons--in virtually all directions.

A list of objectives for the Hadron Absorber to satisfy is given below

- Accommodate a primary beam intensity of 4×10^{13} protons every 1.9 seconds in order to match the production capability of the Main Injector.
- Absorb most of the energy of the non-interacted protons and other strongly interacting particles that reach the end of the NuMI decay pipe, and transfer the resultant heat to a water-cooling system.
- Maintain the number of neutrons exiting the absorber at a level that doesn't represent a prompt radiation hazard in uncontrolled access areas near the hadron absorber.
- Limit the amount of residual radiation on the beam north and beam east sides to ~30 mRem/hr 10 hours after the beam is turned off. These two sides are where people can be present for quick access maintenance or for emergency egress using the walkway that wraps around the absorber and goes up the stairs into the decay tunnel¹.
- Limit the energy loss of muons passing through absorber materials to a level such that the DS muon monitor can function properly².
- Maintain the number of particles entering the surrounding rock walls at a level that doesn't activate groundwater to levels of concern.
- Keep the number of airborne radionuclides produced in the Absorber Cavern low enough that the total number of such radionuclides exiting the vent stack located above the middle of the decay pipe is not in excess of the allowed limit.
- Accommodate the full Main Injector proton intensity under short-term accident conditions of missing the primary target. Short term is defined as less than one hour.
- Assure long-term reliability, stability, and reparability. The facility needs to be usable for a minimum of 10 years.
- Minimize the cost and difficulty of decommissioning the equipment and shielding, when the time comes that the NuMI facility is no longer in use and the decision is made to no longer run the sump pumps and the ventilation systems.

¹ See later for mention of a catwalk that would serve as this walkway.

² This is of particular relevance with the LE option for the neutrino beam.

Absorber Design Parameters, Then and Now

In the time of the November, 1998 TDR the absorber conceptual design³ consisted of a water-cooled aluminum core 24" wide, 36" tall, and 96" in length. It was followed by a steel core with the same transverse dimensions, with length 9.5'. The core had next to it 7 layers of 9.125" thick CCS steel⁴ on the beam east side and underneath, 6 CCS layers on the beam west side, and 8 CCS layers on top. Outside the steel was 3' of concrete block. In the longitudinal direction, there was the 8' of aluminum, 9.5' of steel in the core, followed by two CCS layers of steel, and 3' of concrete.

Since then our design has switched from purchase of CCS steel for the bulk steel, and now uses Duratek blocks⁵; these have dimension 52" x 52" x 26". Excursions of errant beam striking the core became a concern; with NuMI Change Request #43 we increased the transverse core size from 24" x 36" to 42" x 48"—to match the phase space acceptance of the horn protection baffles projected to the absorber position. In the Fall of 2000 we arranged that the IHEP⁶ group do a conceptual engineering design of the absorber materials needing active cooling. The report resulting from this design effort is NuMI report B-652. IHEP increased the transverse core size to 52" x 52" (since that matched the transverse dimensions of the Duratek blocks).

The IHEP study's parameters, then, are a core 52" x 52" in the transverse direction. The core consists of 8 water-cooled aluminum modules, each 12" in length, and one water-cooled steel module. For their study they wrapped this transversely with Duratek blocks 52" thick. Longitudinally, they had the 8' of aluminum and 1' of steel in the core, followed by 6.5' of steel⁷ that wasn't actively cooled⁸.

The method of reparability favored by IHEP was extraction of a water-cooled aluminum module⁹ from the side (together with a 52" x 52" x 12" piece of steel next to it). When their study started they considered extraction from the top, but the removal of the building crane from the Absorber Cavern during the WBS 1.2 tunneling contract negotiations precluded that possibility. After report NuMI B-652 was issued, considerable effort was devoted to studying various options for modifications to the Absorber Cavern--in order to facilitate side extraction of modules--but it was concluded that such modifications would

³ See report NuMI B-493, "Absorber Conceptual Design for the 11/98 DOE Baseline Review", 4/30/99.

⁴ Continuous Cast Salvage steel.

⁵ The cost of these is \$1, plus shipping from Oak Ridge, Tenn.

⁶ Insitute of High Energy Physics, Protvino, Russia.

⁷ Three 26" thicknesses of Duratek blocks.

⁸ IHEP paid limited attention to the full set of shielding requirements. Report NuMI B-727 considered the shielding requirements for an absorber with cylindrical symmetry. It has provided the basis of the dimensions we have chosen, since we haven't had time to do a MARS study with a rectangular geometry that matches our latest design. The current design adds 3' of concrete shield block at the downstream (beam north) end.

⁹ This could also be the one water-cooled steel module. However, we think it more likely it would be one of the aluminum modules at the peak of the energy deposition.

be too costly¹⁰. The Absorber design now assumes reparability via extraction of the core from the beam north end (i.e. downstream). The 11/98 TDR went into no detail regarding how the core could be serviced and repaired, if necessary, but otherwise assumed that the building crane would be used to access the core from above.

The outer shielding of the current design is based upon the shielding study described in NuMI report B-727. It also must satisfy the constraints of fitting in the Absorber Cavern whose dimensions and position are those from the December, 2000 negotiations with SA Healy.

Material Handling

For the 11/98 baseline cost for WBS 1.1.4 the material handling assumptions were 1) use of the MINOS shaft crane to go from the surface to the tunnel with the level floor that goes to the MINOS near detector cavern, 2) use of a rented electric winch with a 700' long cable to negotiate the 650' long, 10.8% sloped tunnel up to the level of the NuMI Absorber Cavern, 3) a riggers "pull bar" to take a load from the top of the ramp into the Absorber Cavern, and 4) use of the building crane to install objects. The only engineering that went into the material handling assumptions was 1) getting a quote on a rented winch and 700' cable for 3 months, and 2) getting a quote on a wheeled cart that could carry a 15 ton load. That cost estimate lacked a number of safety items now deemed necessary; it didn't even have brakes on the wheeled cart.

At the time of the 11/98 estimate it was envisaged that there would be a window of opportunity of several months for absorber installation where relatively uncontested use of the MINOS shaft crane would be available after Beneficial Occupancy (B.O.). This was because it was predicted that the installation of the support framework for the Near Detector steel and scintillator would take place after B.O. However, the current plan for the installation of the support framework is to incorporate that work into the Outfitting contract (for the tunnels and service buildings); therefore, right after the Beneficial Occupancy date, installation of the Near Detector steel and scintillator goes full steam for 9 months and assumes heavy crane usage for two shifts a day. Another new development since 11/98 is the need to install the Hadron Hose elements from both ends of the Decay Pipe; this also is predicted to take 8-9 months.

The plan for material handling for the absorber elements has now had serious engineering attention devoted to it. Additional safety has been built in—especially the addition of brakes to the transport cart. Concern about the possibility that the 700' long cable could snap while under tension has led to the addition of a chain link fence along the 650' ramp—to make a people space on one side¹¹ and an equipment space on the other. It has also led us to provide a 3-sided containment for the cable itself, to provide a protective housing for the ramp winch operator, and to provide concrete shield block "runaway load

¹⁰ Experience with adding cooling water pipes next to the Decay pipe steel convinced us of this.

¹¹ It is assumed that it is necessary to provide an emergency egress route leading up this ramp, through the Absorber Cavern, and up the Decay Pipe tunnel to the Target Hall shaft.

stoppers” at the bottom of the ramp. There are now two winches¹², one for the ramp and the other to pull the loaded cart into the Absorber Cavern; both are considered now to be purchased items. They will have identical drive motors; therefore, the second one has a motor that can serve as the spare for the first. There are now two load transport carts, and the carts ride on tracks that are installed up the ramp. A turntable is planned where the transition from one winch to the other occurs, so that the loaded cart can be turned from one cable angle to the other¹³.

In the Absorber Cavern the removal of the building crane was accompanied by a lowering of the ceiling height from 32.5’ to 20’; the floor elevation stayed the same. To install shielding blocks we now plan to erect a crane that employs two, 10 ton telescoping hydraulic lifting jacks—at either end of a bridge that is designed to clear the rock ceiling by only two inches at full lift height¹⁴. The bridge will support a low-headroom lifting fixture that engages the lifting pins in the Duratek blocks¹⁵. Transverse positioning on the bridge will be done with a hydraulic cylinder mounted on the bridge¹⁶. Longitudinal motion of this crane will be accomplished by installing special rails¹⁷ and by employing hydraulic cylinders that expand and contract along the rail; these cylinders will have a four foot reach. This substitute crane will be much slower in operation than a normal building crane; this difference in speed results in increased expenses for material handling.

Another consequence of the change to a floor-mounted crane is that the crane supports on the beam east side take up floor space. At floor level, the free space from the crane support to the beam east wall is 20”. This is less than OSHA standards for an access path; our solution to this problem is to plan a raised catwalk for that side of the Cavern. Because of the nature of the crane supports, they are narrower at the top than they are at the bottom. A catwalk running from the elevation of the decay tunnel floor, along the beam east wall, and a set of stairs at the back of the Absorber Cavern, could be wide enough to satisfy the OSHA requirement of 28” width.

The Decay Pipe (WBS 1.1.4 & WBS 1.2)

¹² Previously, the rented winch was quoted to have an average cable speed of 40 feet per minute. With the winches now planned, the cable speed is listed as 31 fpm.

¹³ A separate effort is pursuing the possibility of dispensing with the winches for negotiating the ramp, and instead using one of the Fermilab magnet movers to provide the motive power. The people investigating this are Sam Childress and Mike May.

¹⁴ The possibility that four jacks instead of two might be needed for stability for loads whose center of gravity is difficult to locate right under the bridge, is being investigated, but hasn’t been costed.

¹⁵ In this configuration the block could not be lifted from a position where it rested on the floor; it would have to first be staged to a higher elevation by the use of slings.

¹⁶ This hydraulic cylinder has to be manually moved along the bridge in order to provide full east-west coverage.

¹⁷ These rails have to be supported off of the floor at an elevation of 6”, by means of additional supports, in order to provide the full reach in height necessary to place the top Duratek blocks on the Absorber.

The scope of WBS 1.1.4 includes the design, fabrication, and installation of the ends of the Decay Pipe. As such, it includes the engineering note that must be submitted to satisfy ES&H review for such a large vacuum pipe. WBS 1.1.4 also includes the engineering note that describes the shell calculations for the pipe itself, and which is necessary for ES&H review of that design. However, the actual design of the decay pipe is to be done by the tunnel contractor, SA Healy (actually, its sub-contractor for the decay pipe--Chicago Bridge & Iron--does the design). They are contractually responsible for that design; their design must meet Fermilab approval, and must pass the requisite ES&H review. WBS 1.1.4 provides the funds for the Fermilab engineer who will be charged with taking the decay pipe design notes from the contractor, and turning them into a Fermilab engineering note that will be submitted for ES&H review.

An addition to the WBS 1.1.4 Decay Pipe scope since 11/98 is an access port at the downstream end--meant to allow the introduction of robotic equipment for fixing future vacuum leaks. Such equipment has been successfully used with leaks in buried beam pipes at Fermilab. Although leaks in first time use of the Decay Pipe would be extremely difficult to locate¹⁸, it is assumed that over time leaks would be due to corrosion¹⁹ and would become visible when visually inspected by a television camera robotically operated inside the decay pipe. The addition of an access port--in addition to its own expense--somewhat complicates the shielding arrangement ahead of the absorber²⁰. The shielding in that location must also provide means for a limited repair capability for the DS hadron monitor that is planned for the space between the DS end of the Decay Pipe and the US end of the Absorber core.

An added complication at the Decay Pipe ends is that installation of the Hadron Hose will occur over a 8-9 month period, from each end of the Decay Pipe. At the upstream end of the Decay Pipe, the space upstream of the end of the Decay Pipe now must accommodate the air handling equipment that provides the air flow for removal of heat from the steel shielding in the Target Hall that is heated by the beam and must also maintain tight dimensional tolerances.

¹⁸ Leaks would be difficult to locate in first use of the Decay Pipe because of its length and size, the level of vacuum needed, and the surrounding concrete shielding.

¹⁹ The water coming in through cracks in the tunnel walls will provide plenty of humidity, if not actual liquid water. In fact, water entering the tunnel is built into the calculations of radionuclide build up in the groundwater surrounding the tunnel, and is therefore almost a requirement.

²⁰ It is useful to consider this shielding to be an extension of the 4.66' thick concrete shielding surrounding the decay pipe just upstream of the Absorber Cavern. It is there principally for the same reason—to protect the groundwater in the rock just adjacent. It can be a bit thinner, because the rock is further away.